A Novel Non-Destructive Grading method for Mango (*Mangifera Indica L.*) using Fuzzy Expert System

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***Abstract*— Mango (*Mangifera Indica L.)* sorting is the most desired expertise in the evaluation of automatic mango grading systems. Traditionally, Naked eye observation is used to assess the quality of mango. Hence, there is a need to automate grading process. Image processing and machine learning provide one alternative for an automated, non-destructive and cost-effective grading.**

In this paper, proposed methodology is divided in two halves: First part discusses selecting healthy mangoes and then classifying it into ripe and unripe category. Second part talks about grading mangoes based on its size. The image database is used to analyze performance of CIELab colour space and to find colour ranges for different regions of mango. CIELab colour model with Dominant density range method is used for colour feature extraction which easily discriminate colour and classify healthy and diseased mangoes. Same method is used to classify Healthy mangoes in ripe and unripe category. Rest of work is devoted for size measure evaluation using fuzzy expert system for grading of mango. Size feature is calculated using ellipse properties in order to classify in different grades. At final stage, size feature is fed to fuzzy expert system for grading. Integration of whole system results 97.47% average accuracy.

***Keywords*— CIELab colour space; Size; Disease Classification; Maturity classification; Mango Grading; Fuzzy Expert system**

I. INTRODUCTION

The kingdom of India rank first in all over world as a mango producer. Mango (*Mangifera Indica L.*) is the extraordinary produce that substantiates the high quality standards and ample of nutrients filled in it. Mango belonging to family of Anacardiaceae is one of the major grown fruit crops in Gujarat. A largest area is being covered under mango cultivation which makes Gujarat a strong mango growing state for economical growth. There are 1,000 varieties of mango cultivated in India but only a small number of varieties are commercially cultivated all over India or in other countries. Gujarat has richest collections of mango cultivators. Mango varieties cultivated in different district of Gujarat include Jamadar, Totapuri, Dashehari, Neelum, Langra, Kesar, Pyari, Alphonso and Rajapuri.

Different exporting state has its own mango varieties with different value parameters like size, colour and texture, shapes with mouth-watering flavor and odor. When mangoes are harvested, they are transported for testing of various quality attributes that determine their price. Based on different country requirements, internationally recognized treatment like Vapor heat treatment, Irradiation and Hot water treatment services have also been set up at different locations in Gujarat [1-2].

Traditionally, grading of fruits is done by trained inspectors which are time consuming, labor intensive and inefficient. Hence, there is a need to automate grading process. Since, 1970's image processing is applied in the agriculture research such as crop assessment, weed identification, quality inspection and grading of fruit crops and estimation of plant nitrogen content. Therefore, Image processing technology which can assess exterior characteristics of mango has some benefits such as objectivity, efficient and low cost.

Different image processing algorithms have been developed by researchers to improve accuracy of grading systems. Nur Badariah Ahmad Mustafa et al. have developed fruit grading system in [4] based on shape and size using Support Vector Machines (SVMs) and quality of grade is evaluated using Fuzzy Inference System (FIS). Misclassification can be reduced in this system by adding other feature like colour and texture. Chokanan Mango's sweetness is determined by colour feature. Sweetness of Mango is evaluated using Digital AR2008 Abbe refracto-meter. Linear regression analysis (LRA) model could be used to analyze Hue, Saturation and Brightness. Hue band was used to determine sweetness from Chokanan Mango images [5].

Rashmi et al. have developed colour and size based grading system [1] and classified mangoes in healthy and diseased category. Otsu segmentation is used for extracting mango region. Then after diameter and area of mango is calculated for size based grading. Size is fed to the fuzzy logic for mango grading. Shape and colour of a fruit are important features for non-destructive grading. In [2], diseased mango's severity is assessed using fuzzy expert system. Mango region

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is segmented using HSV colour model and then mango colour is extracted for disease severity assessment. Colour normalization is carried out to reduce illumination effect prior to feature extraction [3].

An automated Mango grading system is discussed in [6]. This system analyses Mango based on size, colour and skin feature. Size was calculated from area of Mango fruit. Colour and skin feature was calculated from mean value of R, G, and B value of Mango image. From three values, fuzzy rules were considered to compute grade of Mango. Other classifiers like Neural Network, Support vector machine and K-Nearest neighbor can improve accuracy.

Based on maturity level, automatic grading and sorting system of Mango grading was proposed in [7]. CCD camera was used to collect video image of Mangoes and several significant features of maturity level of Mango was obtained. Colour of Mango was estimated using Gaussian Mixture Model. Accuracy can be improved by using Support vector machine and neural network. Gaussian Mixture Model (GMM) and fuzzy logic was combined for size based grading of Mango. Size of Mango was calculated using pixel area covered by Mango [9].

Wavelets are used for coarse and fine grading of Mangoes using shape descriptor and size [8]. Size is important quality feature used by human experts. Different size metrics of mango were analyzed in [10]. They included asymmetrical and statistical method to determine size of fruit.

In [11], mango is graded in different category using colour. Ellipse strip method is used for colour feature extraction and only rectangle region is considered for experiment. Experiment shows that L*a*b* model is most suitable for grading of fruits as compared to HSI and RGB colour model. From the forgoing work it can be inferred that there is no relevant method for disease and maturity classification and size determination. This paper presents solution to the problem face by mango industries.

II. PROBLEM DEFINITION

In agricultural industry, Mango consumers continuously demand better quality Mangoes. Quality of mango is decided by its grading standard, external appearance and shape/size. Grading stages of mango involves separating healthy and diseased mangoes, check either mango is ripe or unripe and grade a mango based on different grading standard.

In Gujarat, Colour grading is still used for quality grading of mango. Colour is the primary feature to classify fruits in different category. Usually the colour grading of mango is evaluated by the experimental sense of grading by a labor's eyes. However, it is very difficult to distinguish individual colour grade from mangoes with similar colour distribution. Uniform colour grading of mangoes through eyes has resulted in a serious problem because of likely misjudgment. Misjudgment may occur due to recurring fluctuations in grading criteria, the finer difference among same type of mangoes from different production areas and the tiredness of labors. These issues motivate intensive research work to implement flexible and effective systems to sort mangoes. In this paper a novel method for Non destructive grading of mango is proposed which grade mangoes in different class based on colour and size measures. Fig. 1 shows system overview.

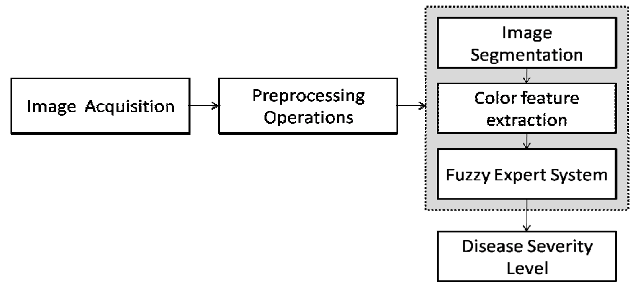

Fig. 1 System Overview

III. MATERIAL AND METHODS

A. Sample collection

For experiment, we have used four varieties of 600 mango samples which were collected from mango orchard of navsari and olpad (Surat District, Gujarat). Mangoes were collected randomly with different degree level of disease, colour and size in the production season 2014.

Fig. 2 Mango Samples (Left to right, Badami, Kesar, Totapuri, Neelum)

B. Image acquisition and image pre-processing

The computer vision system is developed to grade mangoes in different category (Fig.3). Image capturing chamber was embedded with white reflective material for better lighting effects. One 14W CFL lamp (Experimentally, 3W and 7W were used but they didn't not give good illumination effect) was mounted on centre of image capturing

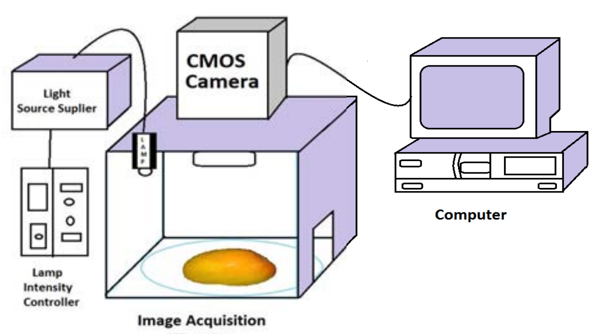

Fig. 3 Proposed Computer Vision System Setup

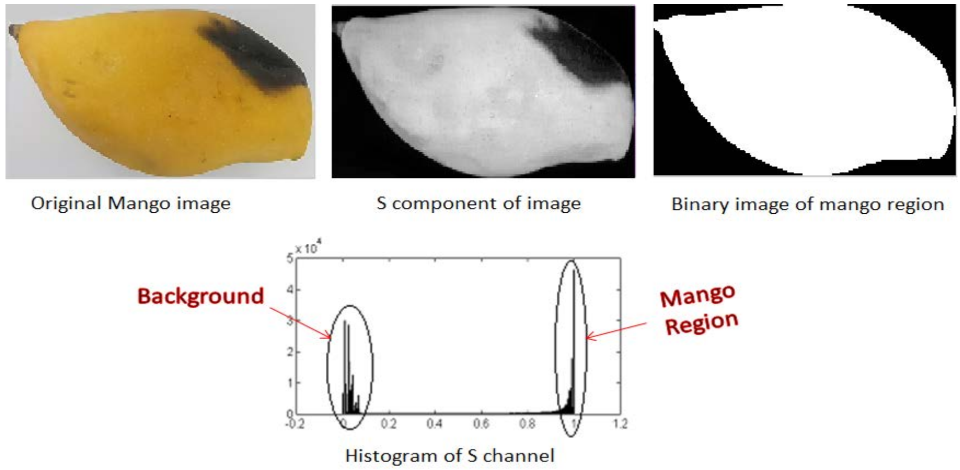

Fig. 4 Segmentation of mango region

chamber as shown in fig.3. Proposed setup captures only one side of mango. For industrial implementation rollers can be employed to rotate the mango to capture the other side using the same setup. Images were captured using camera (Nikon DSLR D90) which was mounted right under the light source for shadow free images. It collects images randomly from perpendicular views with uniformed diffused illumination. The camera was connected to computer which transfers the images through memory card. The dimension of the captured image was 640-480 pixels for rapid feature extraction and processing.

Experiment was conducted in MATLAB (R2013b) with windows platform. The captured image is in RGB colour space which is converted to gray scale. Gray scale image is cropped to reduce computational complexity. To remove noises a simple median filter is applied. This filtering process helped to obtain smooth continuous boundary of the mango. After then, Edges are sharpened to clearly identify the boundary of mango.

C. Image segmentation

Image segmentation is often termed as first stage in image analysis. In this work, image segmentation is implemented to obtain mango region and disease region. In image segmentation, thresholding is used to extract an object from its background by assigning an intensity value T (threshold) for each pixel such that each pixel is either classified as an object or background.

Thresholding usually involves analyzing histogram. Histogram peaks corresponds to regions of image. Image is converted from RGB to HSV for histogram based thresholding. From HSV colour space, saturation channel is used for histogram thresholding. Histogram of S channel (fig. 4) basically shows bimodal characteristics.

Due to the uneven illumination when collecting images in the field, there are some splits between the left peaks of histogram. The left peaks of histogram correspond to the background of image while right peaks of histogram correspond to mango region. After image segmentation binary mage contained mango region (R_{BR}) is obtained by region filling and eliminating holes in the white region. After scanning image from left to right and top to bottom, no. of pixel in white non-zero pixel region is considered as total area of mango.

D. Colour feature extraction

Colour is an important feature in determining maturity and disease of mango. Selecting best colour model is still one of the most difficult tasks in colour image processing. In database, images were in RGB colour model but RGB is a poor choice for colour analysis. Hence, we have used CIE$L*a*b*$ colour channel for colour based classification

$L*a*b*$ colour model is device independent but there is no direct formulas for conversion of nonlinear RGB to linear $L*a*b*$ transformation. So RGB colour space is transformed to intermediate colour space i.e. sRGB or CIEXYZ. This conversion makes data to be device independent. The nonlinear RGB colour space is transformed to linear CIEXYZ using equation (1). CIE$L*a*b*$ is defined in [12]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.00 & 0.066 & 1.116 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{......Eq. (1)}$$

$$L^* = 116\left(\sqrt[3]{\frac{Y}{Y_0}}\right) - 16,$$

$$a^* = 500, \left[\sqrt[3]{\frac{X}{X_0}} - \sqrt[3]{\frac{Y}{Y_0}}\right],$$

$$b^* = 200, \left[\sqrt[3]{\frac{Y}{Y_0}} - \sqrt[3]{\frac{Z}{Z_0}}\right]. \quad \text{....Eq. (2)}$$

Where $\frac{Y}{Y_0} > 0.01$, $\frac{X}{X_0} > 0.01$ and $\frac{Z}{Z_0} > 0.01$. (X_0, Y_0, Z_0) shows X, Y, Z values for standard white.

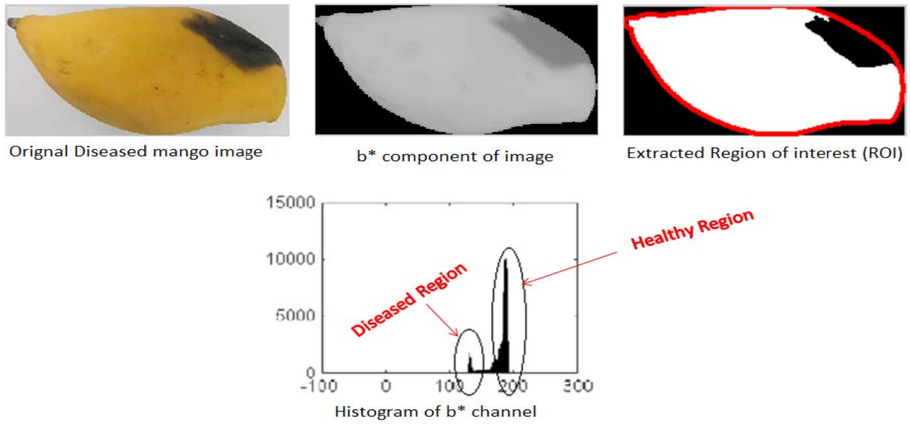

Fig. 5 Segmentation of disease region

1) Healthy and diseased mango classification

Binary image of mango region which was obtained in previous section is multiplied with b component of lab image which called as masking of image. From L*a*b* colour space, b* channel is used for histogram thresholding. In L*a*b* image, b* channel can detect the disease area from masked image. Histogram of b* channel (fig. 5) basically shows bimodal characteristics. From histogram, left peak corresponds to diseased region and right peak corresponds to healthy region of mango.

Reason for choosing black and brown pixel for disease classification is based on general behavior of mango disease.

TABLE I PROPOSED DOMIANAT DENSITY RANGE METHOD

Algorithm : Dominant Density Range Method. This method – find the range of dominant pixels based on density of pixel from image $I(x, y)$

Input:

- $I(x, y)$, a no. of mango samples

Output:

- Classification of mango in different class label

Method:

for $i = 1\ to\ k$ **do** // k , no. of mango samples

--Acquire the sample images $I_i(x, y)$
--Apply pre-processing steps
--Transform the pixel values RGB to CIELab colour space
--Calculate dominant pixel density area $A = \sum_{x,y} I(x, y)$ using histogram
--Calculate the ratio of the pixel area falling in different Range*
--Evaluate class label based on membership value of ratio of the pixel area

end for

The mango disease classification is implemented with a threshold set according to the colour value on b* channel. Range of healthy and diseased is given as below:

$$\begin{cases} 120 \leq b^* \leq 140 & Diseased \\ b^* > 140 & \text{Healthy} \end{cases}$$

Threshold is decided using dominant density range method which is shown in below Table I. Algorithm assumes that there is only single object in the image.

From the fig. 5, it can be seen that diseased region can be well detected from region of interest. Infected mango region (R_{IR}) is obtained by scanning only region of interest from left to right and top to bottom, no. of zero pixels in white regions is considered as diseased area of mango.

Severity of disease is measured in terms of percentage by taking ratio of infected mango region (R_{IR}) to binary image of mango region (R_{BR})

$$Disease\ severity\ (\%) = \frac{R_{IR}}{R_{BR}} \times 100 \quad \text{……Eq. (3)}$$

Where R_{IR} = no. of zero in Extracted region of interest
R_{BR} = Binary image of mango region

In healthy and diseased mango classification, if percentage of disease severity of mango is greater than or equal to T (threshold value) then it will be considered as diseased mango and rejected for further processing else it will be classified as healthy mango.

2) Maturity classification of healthy mango

From the previous section, healthy mangoes will be further classified in two categories namely, ripe and unripe. In L*a*b* colour model, b* channel effectively classify disease and healthy mango using dominant density range method but b* channel fails for maturity classification of mango.

In L*a*b* colour space, a* channel is used for finding maturity of mango. Maturity of mango is measured in terms of percentage of pixel falling in pre-specified threshold. From the experiment, results shows that a* channel is very effective for

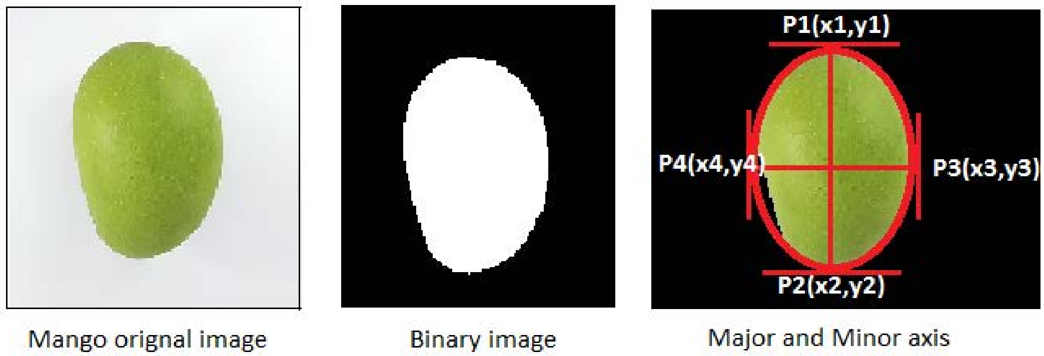

Fig. 6 Major and Minor axis representation on mango

maturity classification. Dominant density range method is used for finding range of ripe and unripe mango classification which is discussed in table I.

Maturity classification of mango is implemented with a threshold set according to the colour value on a* channel. Range of ripe and unripe mango is given as below:

$$\begin{cases} 100 \le a^* \le 125 & Unripe \\ a^* > 125 & Ripe \end{cases}$$

E. Size feature extraction

Mango shape is almost similar to ellipse shape rather than circle. So the Size evaluation is done by approximating the mango fruit image to that of an ellipse [13]. Assume mango's orientation is vertical. Let, P1 (x_1, y_1) is the mid-point of line joining the column maximum points and P2 (x_2, y_2) is the mid-point of line joining the column minimum points of the boundary of mango fruit. The distance between these two points is taken as the length of the major axis of the ellipse encompassing the fruit and is given as,

$$2a = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad \text{......Eq. (4)}$$

The distance between the row minimum point P3 (x_3, y_3) and the row maximum point P4 (x_4, y_4) is considered to be the length of the minor axis and is given as,

$$2b = \sqrt{(x_4 - x_3)^2 + (y_4 - y_3)^2} \qquad \text{......Eq. (5)}$$

This method is applied only when the mid-point of the line joining P1 and P2 nearly coincides with the line joining mid-point of P3 and P4.Illustration of ellipse properties is shown in fig. 6. Major and minor axis of mango is extracted as a size feature and fed to the fuzzy logic for size based grading.

F. Fuzzy Expert System (FIS)

Mangoes are categorized as small, medium, big and very big depending on major and minor axis length of mango. Due to the different varieties of mango major and minor axis length are normalized to simplify computation. Fuzzy expert system or fuzzy controller or fuzzy inference system is applied for mango size based grading. This system is chosen because it represents high-quality approach when human knowledge needs to be integrated into the decision making process. This approach can help to standardize the grading process. Normalized major axis and minor axis length is fed to the Fuzzy inference system (FIS). Procedure for developing Fuzzy Inference system (Fig. 7) for grading of mango is implemented with MATLAB 2013b [14].

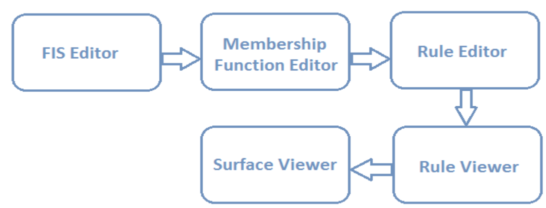

Fig. 7 Fuzzy Inference system

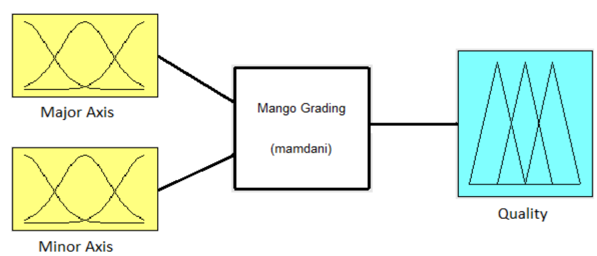

Fig. 8 Fuzzy Inference System for Mango Grading

The procedure consists of three key steps: Input and output of membership function editor, fuzzy rule in rule editor, rule and surface viewer. Rule based Fuzzy inference system is developed to grade mango fruit in four quality grades namely, Poor (Q1), small (Q2), medium (Q3) and Excellent (Q4) based on size. The mango based fuzzy inference system is shown in fig.8.

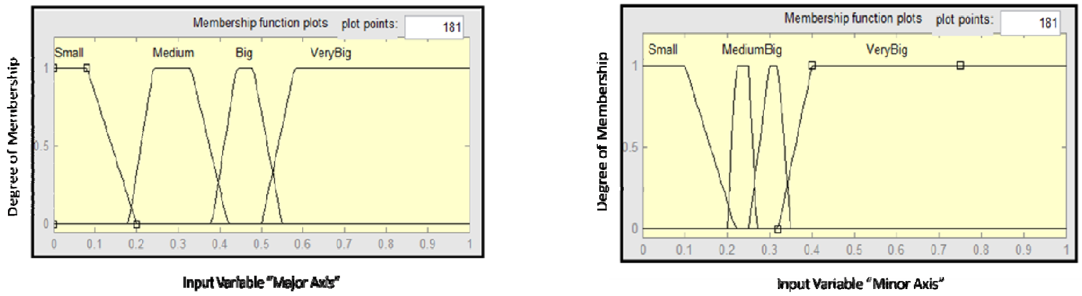

Fig. 9 Major and Minor axis representation on mango

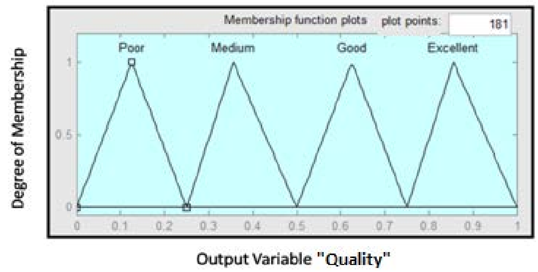

Fig. 10 Membership function of output variable quality

Membership function of major and minor axis length and Quality are shown in fig. 9 and 10. Total 16 if-then-rules are created based on two inputs (major and minor axis) and one output (Quality). The fuzzy rules are shown in Table II. Examples of few fuzzy rules are shown in Table III.

TABLE II FUZZY RULES

Major axis (M) / Minor axis (N)	M1	M2	M3	M4
N1	Q1	Q1	Q1	Q1
N2	Q1	Q2	Q2	Q2
N3	Q1	Q2	Q3	Q3
N4	Q1	Q2	Q3	Q4

M1: Small
M2: Medium
M3: Big
M4: Very Big

N1: Small
N2: Medium
N3: Big
N4: Very Big

Q1: Poor Quality
Q2: Medium Quality
Q3: Good Quality
Q4: Excellent Quality

In rule viewer (Fig.11) inputs and output column shows Major axis, Minor Axis and Quality. Output column gives defuzzification output using centroid method. Result of defuzzification from rule viewer in fig. 11 is shown where value of Major axis is 0.4583 and Minor Axis is 0.5.The classification of mango is determined by crisp value shown in Table IV.

TABLE III FUZZY IF-THEN RULES

Rule 1 If Major Axis is small and Minor Axis is small then Quality is poor	**Rule 12** If Major Axis is medium and Minor Axis is large then Quality is Medium
Rule 4 If Major Axis is small and Minor axis is very big then Quality is Poor	**Rule 16** If Major Axis is very big and Minor Axis is very big then Quality is Excellent

TABLE IV DEFUZZIFICATION RESULTS

Defuzzification Output	**Quality Grade**
(Quality Output < 0.25)	Poor (Q1)
(Quality Output > = 0.25) && (Quality Output < 0.5)	Medium (Q2)
(Quality Output < = 0.5) && (Quality Output < 0.75)	Good (Q3)
(Quality Output >= 0.75)	Excellent (Q4)

IV. RESULTS AND DISCUSSIONS

This section consists of three parts (i) Performance analysis of CIELab colour space with proposed dominant density range method for disease classification (ii) Performance analysis of CIELab colour space with proposed dominant density range method for maturity classification (iii) Fuzzy expert system for evaluating size measures for size based grading of mango.

To evaluate the performance of proposed algorithm, three performance metrics are defined. Accuracy measure of classification is given by Eq. (6),

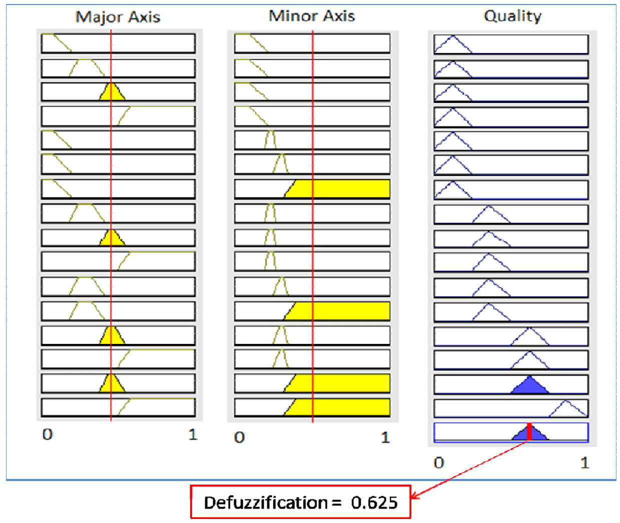

Fig. 11 Defuzzification results from Rule Viewer

$$\eta(\%) = \frac{m-n}{m} \times 100 \qquad \text{....Eq. (6)}$$

Where m = total no. of test images
n = total no. of missclassified images

A. Performance analysis of CIELab colour space with proposed dominant density range method for disease classification

We evaluated the performance of CIELab colour space with proposed method on disease classification problem using training and test samples. Experiment was performed on b* channel to establish relationship between healthy and diseased region. The test results of classification are shown below. Table V shows a confusion matrix showing classification accuracy of healthy and diseased mango classification.

TABLE V CONFUSION MATRIX FOR HEALTHY AND DISEASED MANGO CLASSIFICATION

From/ To	Estimated		Total	η(%)
	Healthy	*Diseased*		
Healthy	469	02	471	99.57%
Diseased	03	50	53	94.33%
Total	473	51	524	96.95%

B. Performance analysis of CIELab colour space with proposed dominant density range method for maturity classification

Experiment was performed on a* channel to establish relationship between unripe and ripe region. By the experiment, results shows that a* channel is good for maturity classification as compared to b*. Table VI shows a confusion matrix showing over all classification accuracy of unripe and ripe mango classification.

TABLE VI CONFUSION MATRIX FOR UNRIPE AND RIPE MANGO CLASSIFICATION

From/ To	Estimated		Total	η(%)
	Unripe	*Ripe*		
Unripe	310	05	315	98.41%
Ripe	01	155	156	99.35%
Total	311	160	471	98.88%

C. Performance evaluation of Fuzzy expert system for size measures

Performance of fuzzy inference system evaluated using ellipse properties. According to results Fuzzy expert system gives best performance. Table VII shows confusion matrix for size based grading.

TABLE VII CONFUSION MATRIX FOR SIZE BASED GRADING

From/ To	Estimated				Total	η(%)
	P	*M*	*G*	*E*		
P	58	04	0	0	62	93.54%
M	03	178	01	0	182	97.80%
G	0	04	204	0	208	98.07%
E	0	0	02	63	65	96.92%
Total	61	186	207	63	517	96.58%

P: Poor M: Medium G: Good E: Excellent

V. Conclusion

An application of image processing based technique is developed for non-destructive grading of mango. L*a*b* colour model is used with proposed dominant density range method to represent colour information of object. This algorithm is developed to test the performance of CIELab colour space for disease and maturity classification. The proposed algorithm detects disease using image segmentation. Accuracy of proposed algorithm is depends on success and failure of image segmentation.

An experimental result shows that overall accuracy of disease classification is 96.95% and for maturity classification, overall accuracy is 98.88%. These results shows that CIELab colour space have good colour discrimination power as compared to other colour space and more robust to lighting condition.

Ellipse properties like major axis and minor axis are used to extract the size feature of mango for size based classification. Ellipse is approximated on the boundaries of mango. Ellipse feature are evaluated by fuzzy expert system or fuzzy inference system to grade mango in different quality (poor, medium, good, and Excellent). Performance of Fuzzy logic is good to classify mango based on size with overall accuracy 96.58%.

Integration of whole system results 97.47% average accuracy. The system is very effective and fairly accurate solution to automate Mango sorting. This system can be easily adapted for grading other kind of mangoes like, Rajapuri, Alphonso, and Pyari.

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References

[1] Rashmi pandey, Nikunj Gamit, Sapan Naik ,"Non-destructive Quality Grading of Mango (Mangifera Indica L.) based on CIELab colour model and Size",ICACCCT 2014,IEEE, May 2014(Accepted).

[2] Rashmi Pandey,Nikunj gamit, Roma marfatia,"Non-destructive method for mango (Mangifera Indica L.) disease sevrity assesment using fuzzy expert system",ERCICA 2014,August 2014 (Accepted).

[3] Harjoko, Agus, and Abdullah Abdullah. "A Fruit Classification Method Based on Shapes and Colour Features." *Proceedings of Asian Physics Symposium*. Vol. 8. No. 1. 2012

[4] Mustafa, Nur Badariah Ahmad, et al. "Agricultural produce sorting and grading using support vector machines and fuzzy logic." *Signal and Image Processing Applications (ICSIPA), 2009 IEEE International Conference on*. IEEE, 2009

[5] Khairunniza-Bejo, Siti, and Syahidah Kamarudin. "Chokanan Mango Sweetness Determination Using HSB Colour Space." *Computational Intelligence, Modelling and Simulation (CIMSiM), 2011 Third International Conference on*. IEEE, 2011R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[6] Razak¹, Tajul Rosli B., Mahmod B. Othman, and Mohd Nazari bin Abu Bakar. "Mango Grading By Using Fuzzy Image Analysis."

[7] Nandi, Chandra Sekhar, Bipan Tudu, and Chiranjib Koley. "An automated machine vision based system for fruit sorting and grading." *Sensing Technology (ICST), 2012 Sixth International Conference on*. IEEE, 2012.

[8] Khoje, Suchitra, and S. K. Bodhe. "Determination of applicability of mother wavelet for coarse and fine grading of mangoes." *Advances in Technology and Engineering (ICATE), 2013 International Conference on*. IEEE, 2013.

[9] Nandi, C. S., B. Tudu, and C. Koley. "Machine Vision Based Techniques for Automatic Mango Fruit Sorting and Grading Based on Maturity Level and Size."*Sensing Technology: Current Status and Future Trends II*. Springer International Publishing, 2014. 27-46.

[10] Khoje, Suchitra, and Shrikant Bodhe. "Comparative Performance Evaluation of Size Metrics and Classifiers in Computer Vision based Automatic Mango Grading." *International Journal of Computer Applications* 61.9 (2013): 1-7.

[11] Naik S. and Patel B.,"CIELab based colour feature extraction for maturity level grading of mango (Mangifera Indica L.)",National Journal of System and Information Technology, ISSN : 0974-3308, Volume 7, No. 1. PP. 39-50, June 2014.

[12] Cheng, Heng-Da, X. H. Jiang, Ying Sun, and Jingli Wang. "Colour image segmentation: advances and prospects." *Pattern recognition* 34, no. 12 (2001): 2259-2281.

[13] Rao, P. Sudhakara, and S. Renganathan. "New approaches for size determination of apple fruits for automatic sorting and grading." *Iranian Journal of Electrical and computer engineering* 1.2 (2002).

[14] The Mathworks, Fuzzy Logic Toolbox User's Guide, (Release 2013b)